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Intellectual capital meets Industry 4.0: transforming logistics through bibliometric insights

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Keywords: intellectual capital, intangible assets, Industry 4.0, logistics.
Abstract: This study conducts a comprehensive bibliometric analysis to explore the evolving relationship between intellectual capital and Industry 4.0 within the logistics sector. The research identifies trends, key contributors, and thematic developments in this interdisciplinary field using data from two leading scientific databases, Web of Science and Scopus. The primary objective is to understand the critical areas of intellectual capital—human, structural, and relational—and their application in Logistics 4.0, driven by technological innovations such as cyber-physical systems and digital transformation. The methodology employs established bibliometric techniques, including co-occurrence and thematic mapping, to evaluate research questions addressing publication trends, country contributions, source relevance, and author influence. Data from 2001–2024 for Web of Science and Scopus datasets reveal key insights: consistent publication growth, leading contributions by countries like China and the USA, and the emergence of themes such as sustainability, innovation, and digital transformation. Comparative analysis highlights differences in keyword trends and collaborative networks between databases, with Scopus displaying a notable time lag in topic evolution. Findings emphasise the pivotal role of intellectual capital in driving logistics innovation, underscoring its integration with Industry 4.0 technologies. Limitations include potential database biases and a data lag for 2024. This study is a foundational reference for scholars and practitioners who leverage intellectual capital for competitive advantage in the digitised logistics era.

1 Introduction

The changes accompanying economic transformations have forced the company to adapt to the evolving competitive landscape. In the twenty-first century, a product no longer plays as significant a role in building a competitive advantage, as its features can be easily replicated in other products. Today, the product and service strength is determined by the knowledge used in their creation [1]. Intellectual capital is a significant aspect of the 21st century. In today's rapidly changing business environment, organisations continuously seek new ways to improve their competitive edge and sustain long-term growth. As a result, acknowledging and efficiently utilising intellectual capital has become a crucial factor influencing organisational success [2].

Intellectual capital is integral to Logistics 4.0, a concept that applies Industry 4.0 principles to the logistics sector. The logistics industry has undergone significant changes in recent years due to rapid technological advancements. In production engineering, integrating cyber-physical systems (CPS) has played a vital role in improving the flow of information between execution and decision-making systems. These systems are increasingly important in logistics as well. Technological innovations supporting physical logistics processes have led to systems with advanced computational and communication capabilities, facilitating seamless information exchange between all resources and components of a product. Like the Industry 4.0 revolution in production, Logistics 4.0 represents a shift from hardware-focused logistics to a software-centric, intelligent, service-oriented landscape. The key areas where intellectual capital is closely linked with Industry 4.0 are human capital, relational capital, structural capital, and innovation and knowledge management. The first three fields are the primary components of intellectual capital [1,3,4].

This study is structured as follows: The first part is dedicated to the theoretical background, where we explain the terms “Intellectual capital” and “Industry 4.0” and how they relate to logistics. The second part describes the data collection process and the methodology used in our

bibliographic research. We also describe the research questions of this study. The third part is devoted to empirical results, where we describe descriptives, country/sources/author analyses, and co-occurrence analysis to answer the research questions set in the beginning. The last part is the conclusion of the paper. The main aim of this study is to analyse the intersection of intellectual capital and Industry 4.0 in logistics to help academics and practitioners understand how knowledge assets—such as human, structural, and relational capital—drive innovation and competitive advantage in modern logistics. By identifying key trends, influential contributors, and thematic developments, this research equips academics and practitioners with insights to align their strategies with the evolving demands of digital transformation, fostering more effective applications of Industry 4.0 principles in logistics.

This study investigates publication trends across Web of Science and Scopus, identifies leading countries in research output, determines the most relevant publication sources, highlights influential authors in the field, and explores key trends and themes through keyword analysis. The methodology part of the study formulates research questions.

2 Literature review

Technological innovation, information technology, and economic growth are closely related and can be described as a general concept of a cycle or wave. Each wave represents a distinct phase in a series of technological innovations that create new economic sectors and opportunities for investment and growth. Since the beginning of the Industrial Revolution at the end of the 18th century, researchers have identified six waves [5,6] (Figure 1). The first wave (1785–1845) introduced hydropower, textiles, and iron innovations, focusing on essential goods production and leveraging improved maritime and inland water transport to reduce costs and expand colonial trade. The second wave (1845–1900) saw coal and steam engines driving rail and steamship expansion, opening new markets and boosting textile production through mass-produced cotton. Electrification defined the third wave (1900–1950), enabling urban transport systems, machinery, and the automobile industry, which enhanced passenger and freight mobility. The fourth wave (1950–1990) brought innovations in plastics, electronics, and aerospace, with jet engines facilitating global travel. The fifth wave (1990–2020) transformed logistics and communication through information systems, personal computing, and e-commerce advancements. The sixth wave (2020–present), or Industry 4.0, integrates robotics, automation, and digitisation, emphasising sustainability and IT-driven efficiency in operations.

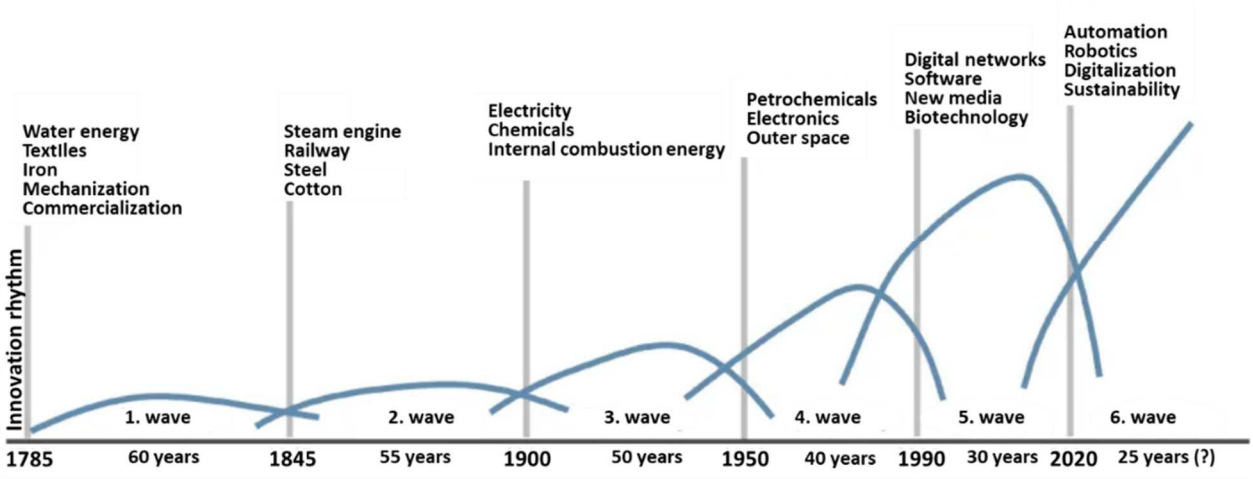

Figure 1 Waves of the industrial revolution

The Industry 4.0 phenomenon emerged in Germany in 2011 as a proposed economic policy development based on the High-Tech Strategy [5,7]. It involves the application of the Internet of Things (IoT) and Internet of Services (IoS) to industrial processes. Using digital technologies that bridge the physical and virtual worlds, manufacturing companies are rapidly transitioning from mass production to custom production [8,9].

Digitally transformed logistics, also known as "Smart logistics," "Logistics 4.0," or "supply chain management 4.0", involves the use of the internet to formalise and standardise logistics business processes. Using ICT technology defines smart logistics as increasing transparency through higher levels of automation and efficiency. This transformation has been driven by the invention of the internet and the 4th industrial revolution (Industry 4.0), leading to the use of Cyber-Physical systems (CPS) for monitoring and controlling the physical flow, a concept referred to as "Logistics 4.0" [3,4]. Intellectual capital is crucial for the success of Logistics 4.0, as it encompasses the required skills, systems, relationships, and innovation capacity to utilise advanced

digital technologies effectively. Human flow, structural, and relational capital interaction empower logistics companies to revamp their operations and excel in the digital logistics era [10]. Intellectual capital is crucial in driving the innovation required for developing and implementing Logistics 4.0 technologies. This involves creating new solutions for automation, AI-based decision-making, and IoT-enabled logistics management. The innovative capacity of a company's intellectual capital is a crucial competitive advantage in Logistics 4.0 [11]. Effective knowledge management within Logistics 4.0 ensures capturing, sharing, and utilising valuable insights from data analytics, customer interactions, and operational experiences. This continuous loop of knowledge flow enhances decision-making and operational efficiency [12]. Recent research emphasises integrating soft skills, advanced technologies, and innovative approaches in modern logistics and supply chain management. Cantoni et al. highlight the significance of soft skills, such as communication and adaptability, in fostering collaboration and addressing complex logistics challenges [13]. Fareed et al. explore how digital technologies like AI, IoT, and blockchain enhance efficiency and sustainability in multimodal logistics operations [14]. Pekarčíková et al. (2024) focus on improving logistics efficiency in storage and picking processes, providing practical insights into specific operational challenges [15]. Pozzo et al. and Rejeb et al. reveal key trends in Logistics 4.0 and IoT applications, highlighting their transformative impact on automation, data-driven strategies, and real-time decision-making in supply chains [16,17]. Straka et al. demonstrate the utility of simulation modelling in optimising production processes, showcasing its relevance for logistics efficiency [18]. Lastly, Núñez-Merino et al. identify research gaps in Industry 4.0 and supply chain integration, providing a roadmap for future advancements [18].

3 Methodology

This study involves analysing literature to gain insights into research trends and gaps in the evolution of intellectual capital concerning Industry 4.0 in logistics. The analysis of published literature data informs the study and highlights vital themes [19]. The research applies mathematical and statistical methods to books and other forms of communication-based on Pritchard's approach [20].

Our research used the standard science mapping workflow created by Börner et al. [21] and improved by Aria and Cuccurullo, Cobo et al., and Zupic and Čater [22-24]. This workflow involves five stages: study design, data collection, data analysis, data visualisation, and interpretation. For our study design, we developed the following research questions:

RQ1: What are the specific trends in publication patterns concerning intellectual capital and Industry 4.0 in logistics in the Web of Science and Scopus databases?
RQ2: Which countries have contributed significantly to research on intellectual capital and Industry 4.0 in logistics, based on publication metrics?
RQ3: What are the most relevant publication sources that advance intellectual capital and Industry 4.0 knowledge within the logistics domain?
RQ4: Who are the most influential authors contributing to intellectual capital and Industry 4.0 in logistics?
RQ5: What are the key themes and emerging trends in intellectual capital and Industry 4.0 in logistics, as reflected in publication keywords?

On August 17th, 2024, we gathered data from the Web of Science and Scopus databases to answer the research questions. Table 1 describes the inclusion criteria for data filtering.

Table 1 Inclusion criteria for data collecting

	Web of Science	Scopus
Keywords	**intellectual capital, intangible assets, industry 4.0, logistics**	
Document Type	**Article**	
Language	**English**	
Subject Area / Category	**Business Finance; Management; Business; Economics; Multidisciplinary Sciences. Exclude all other**	**Business, Management and Accounting; Economics, Econometrics and Finance; Multidisciplinary Limited to the mentioned area**
Total number of selected documents	5,866 documents	739 documents

To better understand the evolution of our research topic, we collected data from all available years without limiting any specific time. We analysed data from 2001 to 2024 for the Web of Science and Scopus. As 2024 is still ongoing, our analyses may be updated by the end of the year. However, we anticipate changes only in the number of published documents, not in the research area itself. We included the year 2024 to capture the most current trends.

We used the latest version of RStudio (2024.04.2+764) to analyse the collected data on a Windows 11 platform. We used the "bibliometrix" package for bibliometric analysis. Data from both databases were imported as ".bib" files, and we utilised the "bibliophily" package in the R command to remove duplicate articles and conduct the analyses [22,25,26].

4 Results

Table 2 provides essential information about the selected samples.

Table 2 Summary of selected samples

	Web of Science	Scopus
Timespan	**2001 - 2024**	**2001 - 2024**
Sources (Journals, Books, etc.)	**618**	**359**
Documents	**5,866**	**739**
Annual Growth Rate %	**19.69**	**18.11**
Document Average Age	**6.39**	**4.9**
Average citations per doc	**18.32**	**27.07**
Author's Keywords (DE)	**15,327**	**2,372**
Authors	**12,893**	**1,915**
Timespan	**2001 – 2024**	**2001 - 2024**

Between 2001 and August 17, 2024, 12,893 authors produced 5,866 documents across 618 sources listed in the Web of Science database. Additionally, for 359 sources listed in Scopus, 1,915 authors produced 739 papers from 2001 to August 17, 2024. Figure 2 illustrates the publication trend for both scientific databases. Both databases show a consistent increasing trend in publications related to intellectual capital in logistics.

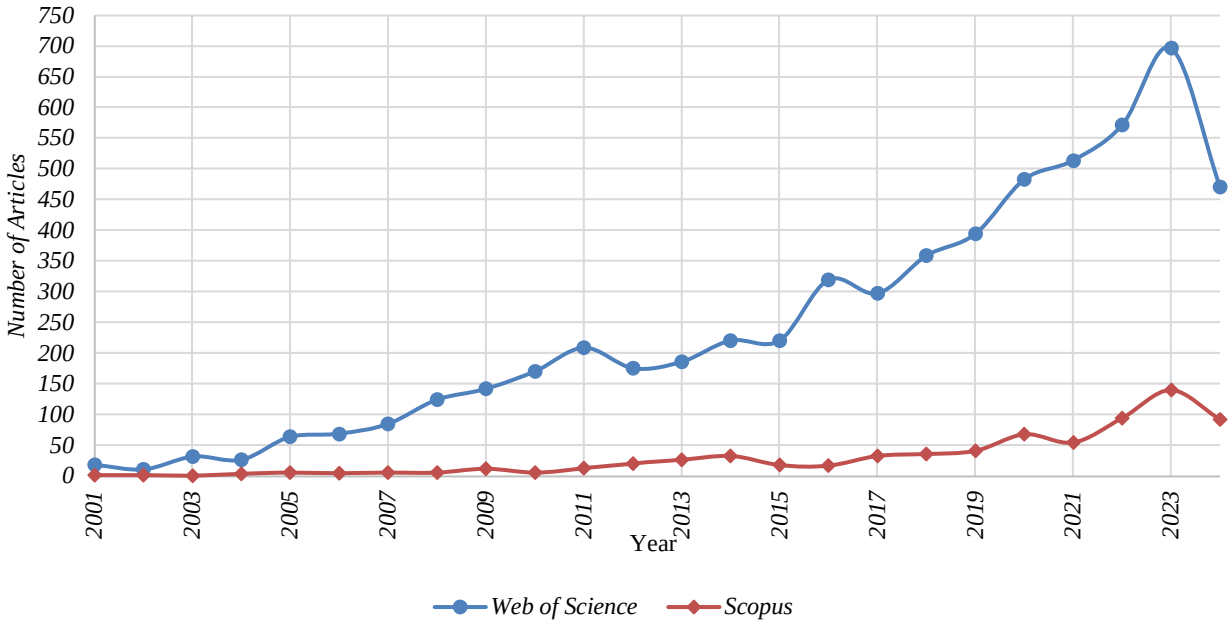

Figure 2 The publication trend. Source: own proceeding

Understanding the creators of these publications is not less important. We provide structural analyses of producing countries, sources, and authors in this case. Based on our findings, the top five most productive countries in the Web of Science are China (2,603 publications), the USA (2,238 publications), India (1,162 publications), the United Kingdom (1,044 publications), and Australia (858 publications). The results for all available countries are illustrated in Figure 3.

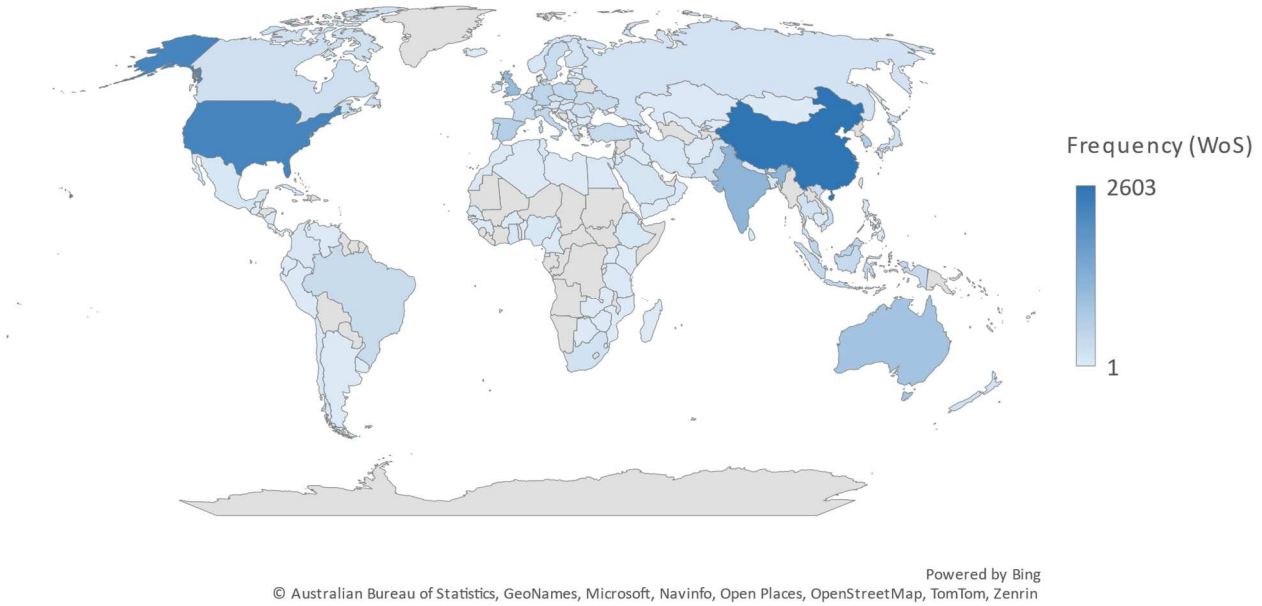

Figure 3 Country scientific production: Web of Science

On the other hand, the top 5 more productive countries are China (198 publications), the USA (131 publications), Italy (130 publications), the United Kingdom (98 publications) and Malaysia (92 publications). The results for all available countries are illustrated in Figure 4.

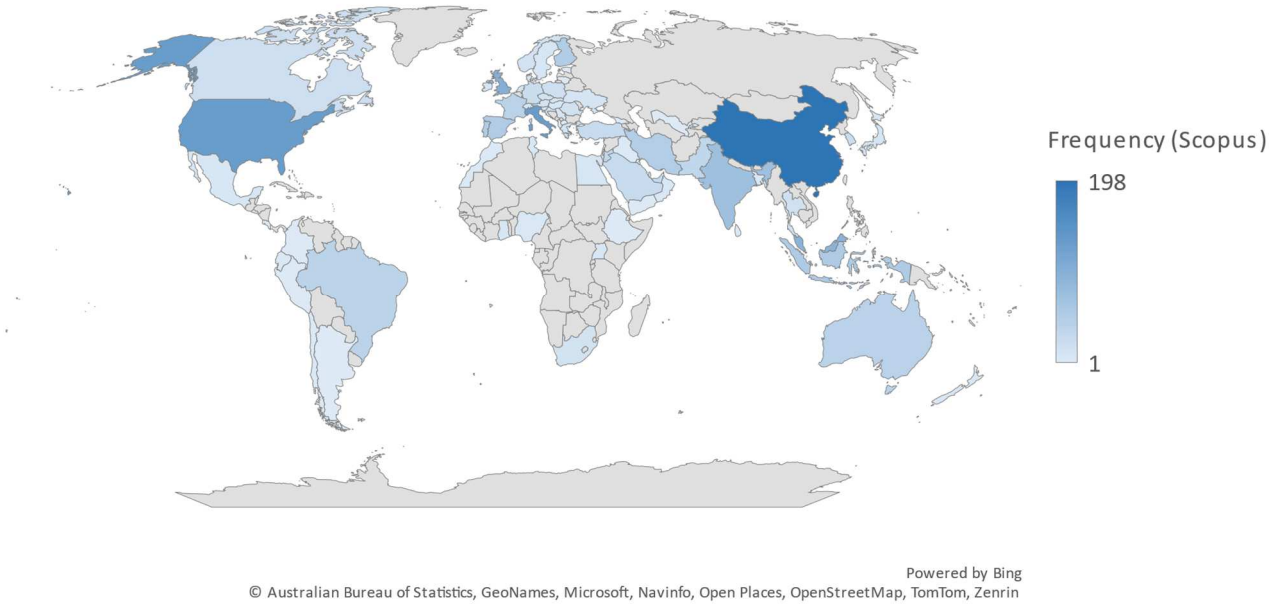

Figure 4 Country scientific production: Scopus

As international collaboration drives the quantity and quality of research, understanding the structure of these collaborative networks is crucial. In the case of the Web of Science, the most frequent research collaborations are between China and the USA (109), China and Australia (57), China and the United Kingdom (51), the USA and Korea (50), and the USA and the United Kingdom (46). The entire collaboration map is illustrated in Figure 5.

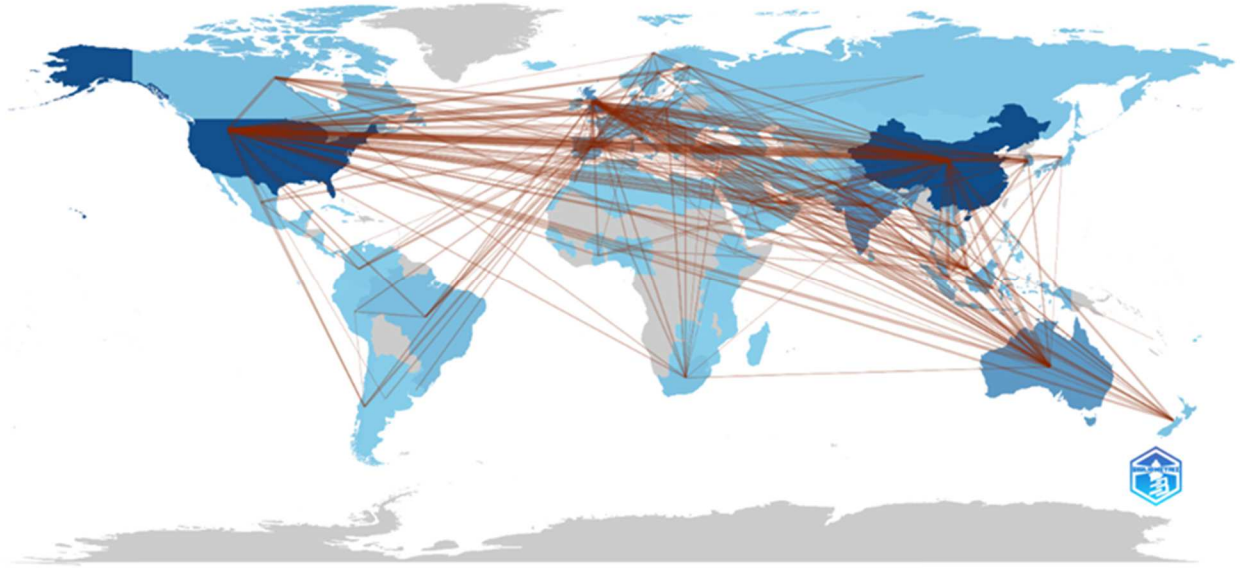

Figure 5 Collaboration world map: Web of Science

The collaboration map in the Scopus sample is the weakest, with lower levels of collaboration. The most frequent research collaborations are between China and Pakistan (10), the United Kingdom and France (10), Italy and the United Kingdom (9), Malaysia and Pakistan (8), and the USA and France (8). The complete collaboration map is illustrated in Figure 6.

Figure 6 Collaboration world map: Scopus

The following essential aspect of every research is the publication sources for these articles. According to our results, the most relevant source in the Web of Science is the "Asia Pacific Journal of Marketing and Logistics," with 1,097 published articles. The second most relevant source is "Supply Chain Management—An International Journal," with 216 publications. The third spot in the top three is taken by "Industrial Marketing Management," with 101 publications. The top 10 relevant sources are illustrated in Figure 7.

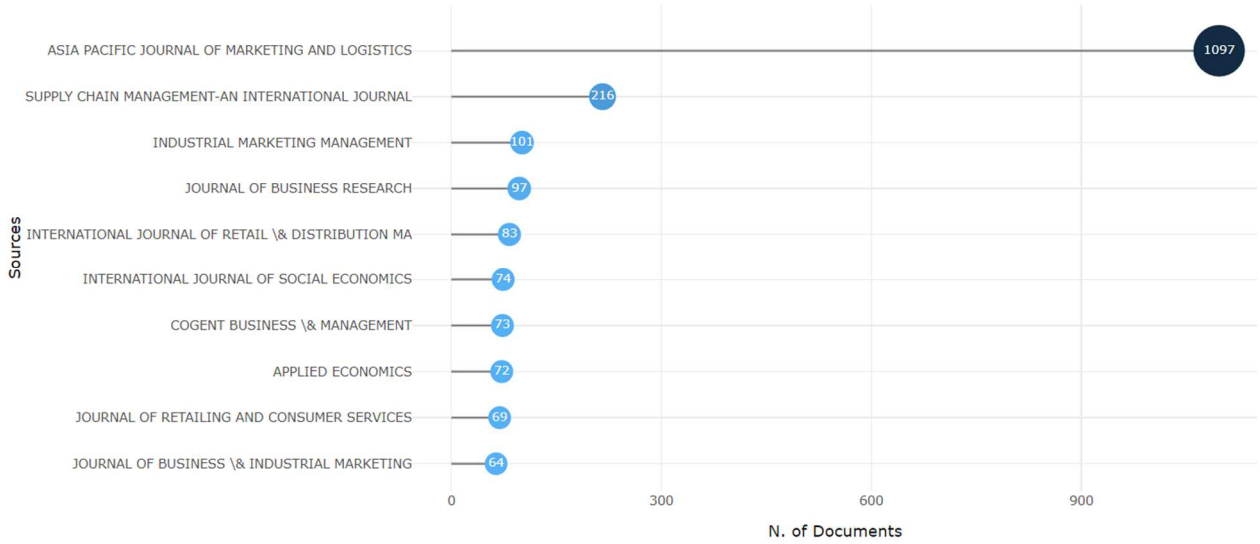

Figure 7 The most relevant source is the Web of Science

In the case of Scopus, the most relevant source is the "Journal of Intellectual Capital" with 62 publications. Following a significant gap in counts, the second most relevant source is the "Journal of Knowledge Management" with 26 articles, and the top 3 is closed by the "Journal of Business Research" with 12 publications. The top 10 relevant sources are illustrated in Figure 8.

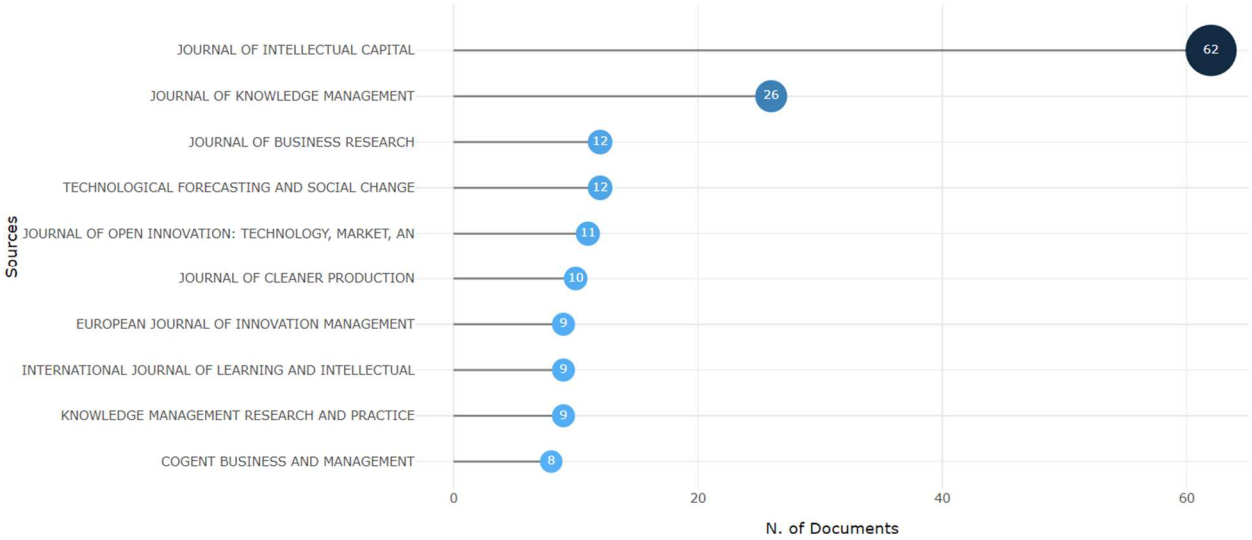

Figure 8 The most relevant sources: Scopus

Based on our findings, the top 10 authors in the case of Web of Science are: Liu Y., Wang X., Li X., Zhang Y., Wang Y., Liu M.T., Wang J., Zhang J., and Li Z. The number of published articles by each of them is illustrated in Figure 9.

In the Scopus sample, the top 10 authors are Lönnqvist A., Laihonen H., Xu J., Bontis N., Grimaldi M., Ramayah T., Sillanpää V., Soewarno N., Al-Hawamleh A., Chatterjee S. The number of published articles by each of them is illustrated in Figure 10.

Furthermore, we examined the country of the corresponding author. We analysed the collaborative patterns among countries to ascertain whether they had publications solely within their own country or if they participated in international co-authorship. We utilised maps to illustrate the collaboration between corresponding authors and countries to gain better insights into these connections. Results for Web of Science and Scopus are illustrated in Figure 11 and Figure 12, where MCP stands for Multiple Country Publications, and SCP stands for Single Country Publications.

The following part of this article provides a co-occurrence analysis, which helps identify the main topics and trends in research. We analysed 15,327 keywords from the Web of Science sample and 2,372 keywords from the

Scopus sample. Table 3 lists the top 20 most frequent keywords for both samples.

Table 3 The 20 most frequently used keywords

Web of Science		***Scopus***	
Keyword	**Frequency**	**Keyword**	**Frequency**
Logistics	**259**	Intellectual capital	**145**
Logistic regression	**241**	Knowledge management	**57**
Supply chain management	**197**	Human capital	**55**
Innovation	**170**	Innovation	**44**
China	**140**	Relational capital	**29**
Consumer behaviour	**136**	SMEs	**27**
Supply chain	**110**	Social capital	**25**
Management	**99**	Intangible assets	**24**
Sustainability	**99**	Firm performance	**23**
Performance	**96**	Performance	**23**
India	**93**	Sustainability	**22**
Entrepreneurship	**91**	Structural capital	**20**
E-commerce	**87**	Competitive advantage	**19**
SMEs	**86**	Organisational performance	**18**
Covid-19	**82**	Financial performance	**17**
Regression	**77**	Value creation	**17**
Customer satisfaction	**73**	Resource-based view	**15**
Reverse logistics	**73**	Business performance	**14**
Trust	**71**	Digital transformation	**14**
Gender	**66**	Corporate social responsibility	**13**

All available keywords are analysed using the co-occurrence method. The keywords were split into three clusters in the Web of Science sample. The first cluster (red) consists of 19 keywords summarising topics related to logistics supply chains and their management. The second cluster (blue) contains 14 keywords describing customer behaviour and e-commerce. The last cluster (green) includes 16 keywords describing corporate governance and competitiveness. The results are illustrated in Figure 9.

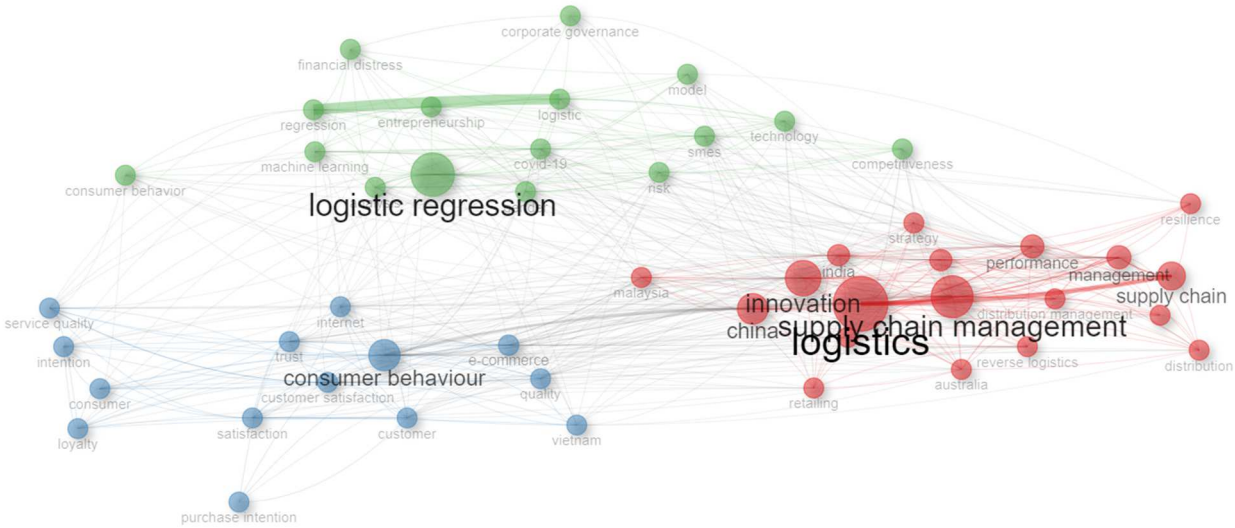

Figure 9 Co-occurrence analysis: Web of Science

Based on the keywords analysis, we created the thematic map for the Web of Science data (see Figure 10) and Scopus data (see Figure 12). All topics were divided into four quadrants based on their relevance and level of development. In other words, we categorised key issues into four groups: niche themes, motor themes, emerging

themes, and basic themes. In the case of Web of Science, logistic regression is the niche theme. Between motor themes belonging to research about consumer behaviour, China and India. Entrepreneurship, SMEs and COVID-19 issues are detected as emerging or declining themes. Basic themes include logistics, supply chain management, and innovation.

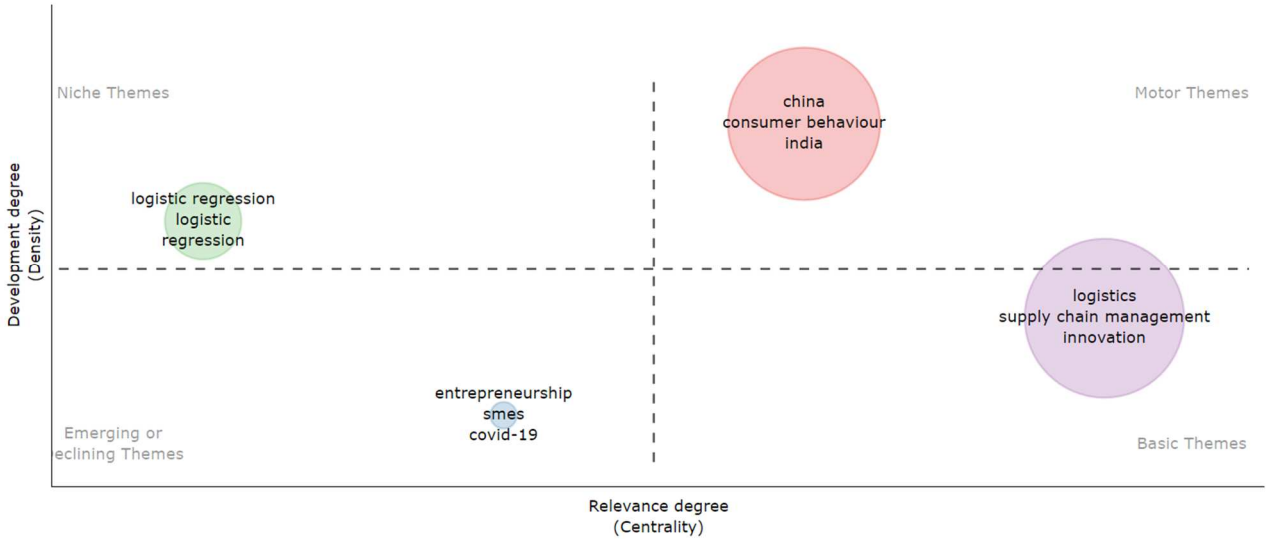

Figure 10 Thematic map: Web of Science

In analysing Scopus, we have identified five clusters. The first cluster (red) consists of nine keywords describing intangible assets and their management. The second cluster (blue) contains eight keywords related to intellectual capital, industry 4.0, and research and development. The third cluster (green) comprises eleven keywords summarising innovations and their competitive advantages. The fourth cluster (purple) includes ten keywords that summarise the topic of value creation and management of intellectual capital and supply chains. Finally, the fifth cluster (orange) contains eleven keywords describing intellectual capital and innovation capability components. The results are illustrated in Figure 11.

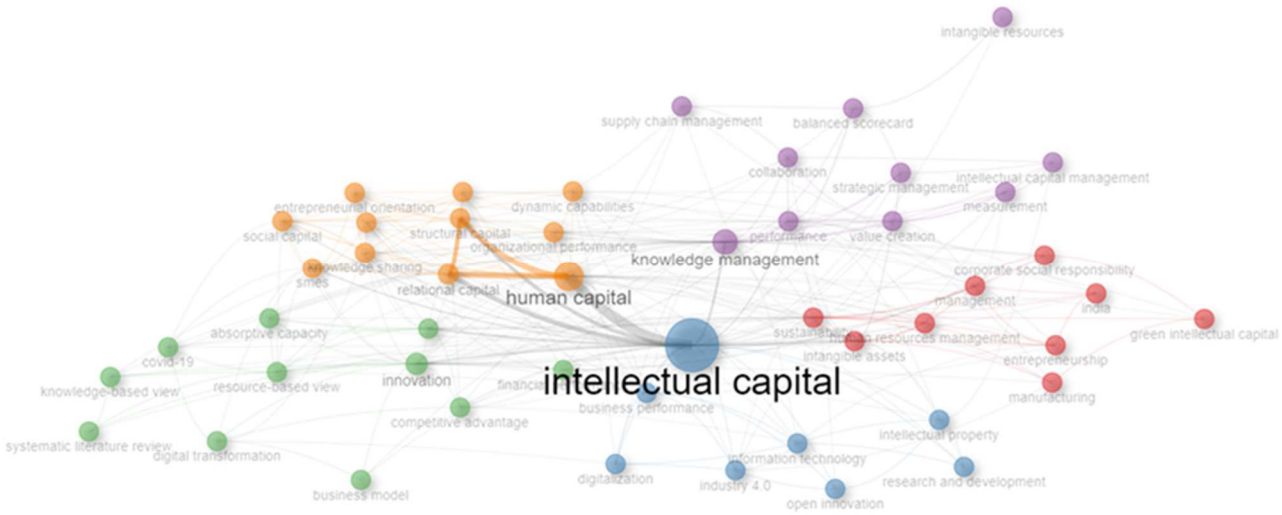

Figure 11 Co-occurrence analysis: Scopus

Scopus's thematic map is broader, as visible in Figure 12. Niche themes include value creation and strategic management research, digitalisation, open innovation, and Industry 4.0. Basic themes include intellectual capital and its components, knowledge management, innovation, intangible assets, sustainability, and corporate social responsibility.

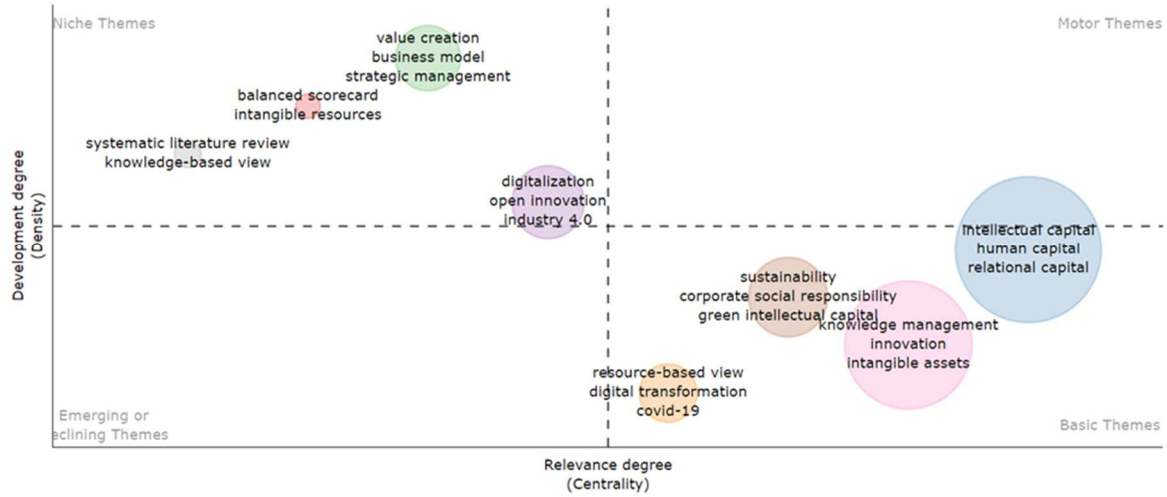

Figure 12 Thematic map: Scopus

5 Discussion

This study provides a comprehensive bibliometric analysis of published research on intellectual capital and Industry 4.0 in logistics based on data from the Web of Science and Scopus databases. The analysis spans all available years, covering 2001 – 2024 for the Web of Science and Scopus. It addresses key research questions to elucidate trends, contributors, and thematic developments within this field.

The first research question (RQ1) examines trends in publication patterns. The findings reveal a consistent increase in publications in both databases, underscoring growing academic interest in integrating intellectual capital and Industry 4.0 in logistics. This upward trajectory reflects the field's relevance in addressing the challenges and opportunities of digital transformation in logistics. The second research question (RQ2) identifies the leading countries in publication metrics. The Web of Science results highlight China, the USA, India, the UK, and Australia as the top contributors. At the same time, Scopus identifies China, the USA, Italy, the UK, and Malaysia as the most productive. Collaboration patterns differ between databases; Web of Science showcases strong international partnerships, such as those between China and the USA. Scopus highlights more regionally focused collaborations, including China, Pakistan, and the UK and France. These findings underscore the importance of global and regional collaboration networks in advancing research. The third research question (RQ3) explores the most relevant sources. In the Web of Science, the "Asia Pacific Journal of Marketing and Logistics," "Supply Chain Management—An International Journal," and "Industrial Marketing Management" emerge as the leading publication platforms. In Scopus, the "Journal of Intellectual Capital," "Journal of Knowledge Management," and "Journal of Business Research" are the most significant sources. These journals play a pivotal role in disseminating research and advancing the theoretical and practical understanding of intellectual capital in logistics. The fourth research question (RQ4) focuses on the most influential authors. In the Web of Science, key contributors include Liu Y., Wang X., Li X., Zhang Y., and Wang Y., among others. In Scopus, prominent authors such as Lönnqvist A., Laihonen H., Xu J., Bontis N., and Grimaldi M. are identified. These authors significantly shape the intellectual landscape of the field. Additionally, an analysis of corresponding author countries highlights the geographical distribution of research leadership and collaboration networks. The fifth research question (RQ5) delves into key trends and themes based on publication keywords. In the Web of Science, keywords cluster into three themes: niche topics such as logistic regression, basic themes like logistics, supply chain management, and innovation, and motor themes such as consumer behaviour and research activity in China and India. Scopus reveals five clusters, with niche themes including value creation and digitalisation, basic themes such as intellectual capital components and corporate social responsibility, and emerging themes like Industry 4.0 and open innovation. These clusters provide a nuanced understanding of the field's thematic evolution, pointing to foundational topics and emerging research frontiers. This study answers critical questions regarding the trends, contributions, and thematic focus of research on intellectual capital and Industry 4.0 in logistics. It provides a valuable resource for academics and practitioners seeking to understand and advance the integration of these concepts in the logistics domain.

6 Conclusion

This study's findings are informative and provide a profound understanding of the evolving relationship between intellectual capital and Industry 4.0 within the logistics domain. Through a comprehensive bibliometric analysis, significant trends and themes have been uncovered, shedding light on the current state of research, its geographical distribution, key contributors, and thematic focus areas.

The analysis revealed a consistent upward trend in publications related to intellectual capital and Industry 4.0 in logistics, highlighting growing academic and practical

interest in the field. However, notable differences between the Web of Science and Scopus databases were observed. For instance, Web of Science demonstrated a longer historical trajectory, while Scopus showed a higher annual growth rate, suggesting a more recent intensification of research activity. This discrepancy underscores the importance of leveraging multiple databases to capture a holistic view of the research landscape.

Geographically, China and the USA emerged as dominant contributors across both databases, reflecting their leadership in technological innovation and logistics research. However, the collaboration patterns differed significantly between the databases. While Web of Science demonstrated robust international collaborations, Scopus highlighted less extensive but regionally focused partnerships. These differences suggest collaboration networks are critical in shaping research productivity and quality. Identifying key sources, such as the Asia Pacific Journal of Marketing and Logistics and the Journal of Intellectual Capital, underscores the field's interdisciplinary nature. These sources are pivotal platforms for disseminating cutting-edge research and advancing the theoretical and practical understanding of intellectual capital in Industry 4.0, bridging domains such as marketing, knowledge management, and industrial logistics. The thematic analysis highlighted the integration of intellectual capital components—human, structural, and relational—with Industry 4.0 technologies. Basic themes such as logistics, supply chain management, and innovation remain foundational, while niche themes like value creation and digital transformation point to emerging research frontiers. The motor themes, including consumer behaviour and sustainability, reflect the field's alignment with broader societal and environmental concerns, emphasising the need for sustainable and adaptive logistics practices. One notable finding is the thematic divergence between the databases. Web of Science prioritises logistics and supply chain management, while Scopus emphasises intangible assets and strategic management. This divergence suggests that the databases cater to slightly different academic audiences and priorities, which may influence the framing and dissemination of research in the field. Despite these insights, it's crucial to acknowledge the study's limitations. Including data up to 2024 may not fully capture ongoing developments, and language biases inherent in the databases may have excluded relevant non-English research. Additionally, the analysis relies heavily on bibliometric techniques, which, while powerful, may only partially account for the qualitative nuances of intellectual capital research. Awareness of these limitations is essential to understand the study's scope and implications comprehensively.

Overall, this study contributes to the growing body of literature by providing a structured and detailed understanding of how intellectual capital underpins logistics transformation in the era of Industry 4.0. The findings are valuable for academics and practitioners, offering a roadmap for future research and practical applications. We hope that future studies could build on this foundation by incorporating qualitative analyses, exploring case studies, and examining the role of intellectual capital in specific logistics technologies, such as blockchain, IoT, and AI-driven supply chain management. These efforts would further enrich the understanding of how intellectual capital drives innovation and competitive advantage in the digital age.

This study has some limitations. First, there is a data lag issue. We chose not to exclude 2024 to ensure we have the most current information available. It's important to note that while the basic information might remain mostly the same, the number of publications could still vary. Second, there is a coverage bias due to the databases needing to cover all languages uniformly. These limitations emphasise the need for cautious interpretation of our findings, particularly regarding the currency of data and the language bias inherent in our database selection.

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